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(54) LOCATING NON-LINEAR JUNCTIONS BETWEEN METALLIC MATERIALS AND/OR SEMI-CONDUCTIVE MATERIALS

(71) We, WESTINGHOUSE CANADA LIMITED, a company organised and existing under the laws of Canada, the post office address of its principal place of business is 286 Sandford Avenue North, Hamilton, Ontario, Canada, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:–

The present invention relates to a method of defecting random elements, such as non-linear junctions between metallic materials and/or semiconductive materials. It is becoming more essential every day to be able to detect and locate devices containing metallic materials or semiconductive materials having non-linear junctions therebetween. Diodes, transistors, semiconductive devices, and corroded joints between the electrical conductors represent some of the non-linear junctions. Such junctions occur in a great variety of electronic and electrical devices and in particular occur in electronic bugs and radio-controlled mechanisms. The detection of these devices using readily available close proximity sensors, which rely on the magnetic and dielectric properties of materials is virtually impossible in buildings and structures. Non-linear junctions which exhibit a square law response with respect to voltage and current across the junction when illuminated by electromagnetic signals, re-radiate harmonics related to the frequency of the illuminating electromagnetic signals. These junctions act as multipliers so that a signal, which may be represented by $E_1 \sin \omega_1 t$, when multiplied by itself in a square law junction, gives the standard square law response of equation 1.

$$(E_1 \sin \omega_1 t)^2 = \frac{E_1^{\,2}}{2}(1 - \cos 2\,\omega_1 t) \qquad (1)$$

The $\frac{E_1^{\,2}}{2}\cos 2\,\omega_1 t$ term gives the second harmonic term.

Higher harmonic terms are produced by a successive self multiplication process.

These signals have been a problem in the low frequency communications bands where power output and transmitter density are high and in the microwave bands where the junctions are most efficient. The above radiated signals are known as inter-modulation interference and the prior art has concentrated on locating these signal sources using the principal that these re-radiated or return signals are harmonics of a single frequency. The prior art therefore has concentrated on detecting the second and third harmonic return signals. One of these apparati which overcomes some of the difficulties associated with magnetic and dielectric detection provides a transmitter for transmitting a single signal of frequency f_o and two receivers which are tuned to receive the second and third harmonics, $2f_o$ and $3f_o$ respectively of the transmitted signal. A pure signal of frequency f_o is employed to illuminate an area suspected of containing non-linear junctions. If the suspected area does not contain non-linear junctions, the area will reflect only a signal of original frequency f_o, which signal is ignored. If the suspected area does contain non-linear junctions, the re-radiated signal will not only contain original frequency f_o, but will also contain harmonics of frequency f_o. These harmonics will be detected by multiple receivers tuned to these harmonic frequencies. The detector contains a transmitter that generates and radiates a pure signal of frequency f_o. This

transmitter is carefully shielded and filtered so as to prevent the leakage of harmonics from the transmitter. The detector also contains two receivers, one tuned to the second harmonic $2f_0$ of the transmitted frequency. The local oscillators of both of these receivers are derived from the transmitted frequency.

However, this apparatus has not been entirely satisfactory since the sensitivity of the apparatus is limited due to the problem of having to decouple transmitter harmonics from the receiver channel as well as to avoid harmonic response in the receiver to the fundamental transmitter frequency. The latter sources of spurious response seriously limit the sensitivity of the apparatus. It becomes increasingly costly to attempt to improve the sensitivity of the device by improving the decoupling of the transmitter harmonics from the receiver channel and/or elimination of harmonics from the transmitted frequency.

The present invention consists in a method of detecting random junctions non-linearly responsive to incident oscillatory energy comprising, radiating energy from a first source of a first frequency f_1 and from a second source of a second frequency f_2 where f_1 and f_2 are not harmonically related, permitting energy from both said sources to impinge on at least one non-linear junction, whereby said junction responds to said energy to produce energy of a third frequency $n_1f_1 \pm n_2f_2$ where n_1 and n_2 are integers.

The method will be described in greater detail with reference to the accompanying drawings in which:

Figure 1 is a block diagram of an apparatus for use in performing the method of the invention;

Figures 2 and 3 are block diagrams of other embodiments of the apparatus.

Figure 4 shows an embodiment of a sonic transponder.

As shown in Figure 1 in block form, the apparatus comprises signal generators 1 and 2, with output carrier frequencies of f_1 and f_2 respectively, antennas 3 and 4 for radiating the carrier signals f_1 and f_2, an antenna 5 which receives signals, returned by a device 8 to be located, to provide an input to a receiver 6, and a display unit 7 which presents the receiver output in a suitable form.

Although items 3, 4, and 5 are shown as separate elements in the figures, it is to be understood that they may be combined into a single unit, such as by the use of a multiplexer.

Various other changes and improvements such as providing frequencies f_1 and f_2 from a single oscillator as well as the local oscillator signal for the tuned receiver are contemplated.

The principle of operation of the apparatus, in performing the method of the invention will now be more fully described with the aid of the following equations.

The expansion of the product of two signals represented by $E_1 \sin \omega_1 t$ and $E_2 \sin \omega_2 t$ is given by equation 2.

$$(E_1 \sin \omega_1 t + E_2 \sin \omega_2 t)^2 = E_1^2 \sin^2 \omega_1 t + 2 E_1 E_2 \sin \omega_1 t . \sin \omega_2 t + E_2^2 \sin^2 \omega_2 t \qquad (2)$$

The squared terms may be expanded to produce

$$\frac{E_1^2}{2} \cos 2 \omega 1 t \text{ and } \frac{E_2^2}{2} \cos 2 \omega 2 t \qquad (3)$$

and the product term may be expanded to produce

$$E_1 E_2 \cos (\overline{\omega_1 - \omega_2}) t - E_1 E_2 \cos (\overline{\omega_1 + \omega_2}) t \qquad (4)$$

Higher order harmonic terms and terms with frequencies given by $n_1 \omega_1 \pm n_2 \omega_2$ (where n_1 and n_2 are integers) are produced in addition to those indicated by equations 3 and 4 by a successive self multiplication process.

The apparatus, by providing two transmitter frequencies, is able to cause the non-linear junction to re-radiate frequencies which are not only harmonics or squared term products as given in equation 3, and as is the case in prior art apparatus, but frequencies which are the sum and difference of the transmitted frequencies or product term frequencies given by equation 4. This allows the apparatus to have unexpectedly higher discrimination and selectivity than prior art apparatus of the same complexity.

It is to be understood that where the term non-linear junctions is used, it is meant to comprise semiconductive junctions such as occur in devices made from semiconducting material for example, transistors, integrated circuits and related devices, semiconductive junctions formed by oxidation products of, metals and related phenomena.

The above apparatus may be adapted for use in location of radio controlled

apparatus, unlicensed or unauthorized equipment, airport surveillance, detection of stolen goods, detection and location of electronic bugging devices and remote sensors placed for intelligence purposes.

A second embodiment as shown in Figure 2 is similar to that shown in Figure 1, except that it shows modulation signals 9 and 10 superimposed on the carrier signals to provide increased sensitivity, in detection and identification by providing improved discrimination and differentiation between desired and spurious signals. With increased power and the increase of sensitivity and discrimination available through the use of modulated carrier signals, the apparatus may be adapted for the detection of aircraft, either foreign or crashed, detection and location of ships over the horizon, and submarines.

The present invention also contemplates the use of carrier modulation schemes to obtain additional information such as range and bearing of the device to be located as well as providing range and bearing selectivity. With range and bearing capability, the above apparatus could be used for the provision of channel markers as an aid to navigation at night and in bad weather, collision avoidance, search and rescue operations, provision of passive markers for surveying purposes, and automatic focusing of movie and television cameras on moving objects or on fixed objects when the camera is moving.

It is also contemplated that devices containing non-linear elements could be placed at mobile or fixed locations for various remote sensing, interrogating control and communication purposes. The above apparatus could then be used for remote sensor interrogation, motion detectors, proximity indicators and fuses, and securing communications by having a sender modulate the mixing efficiency of a diode connected to an antenna which is illuminated by two signals at frequencies supplied by the intended receiver.

In another embodiment of the invention, it is contemplated that the present invention may act as a sonic transponder. The sonic transponder consists of a sound energy to electrical energy converter or transducer 11 as shown in Figure 4. The electrical output of the transducer is fed to a non-linear element 12 which produces currents having frequencies equal to the sums and differences between harmonics of the frequencies of the sound waves 13 incident on the transducer. The transducer converts these currents into sound waves 14 which emanate therefrom in such a manner that the sonic transponder behaves like a sonic rectifier.

In Figure 3, which is similar to Figure 2, the transmitter 2 of frequency f_2 is modulated by a signal 9 with a frequency f_3. The output of the tuned receiver is fed to a phase detector 15 which compares the phase of the signal 9 with the demodulated output 16 from the tuned receiver. The element 5 may be an antenna or a suitable reception transponder. The elements 11 and 12 form the sonic rectifier or transponder. The outputs 17 and 18 are respectively outputs to a range indicator and a direction indicator.

The sonic transponder may be used as a sonic position indicator. The distance between a reference marker containing the sonic transponder and the transmit-receive assembly is obtained from the phase difference between the modulation signal f_3 at the transmitter and its demodulated version at the receiver. The direction of the reference marker is obtained by rotating the directional transmit-receive array consisting of elements 3, 4 and 5 to maximize the demodulated receiver output. If the difference frequency $f_1 - f_2$ is an audio-frequency, it could also be used for direction finding. It can thus be seen that the present invention is capable of operation in air, liquid, gas or solid and may be used to detect man-made devices and natural materials exhibiting sonic rectification.

In summary, the applicant has provided in a preferred embodiment, a first signal generator means providing a first carrier signal having a frequency f_1, a second signal generator means providing a second carrier signal having a frequency f_2, first and second antennae for radiating the carrier signals, a third antenna, and a receiver connected to the third antenna and, tuned to detect signals radiating from any non-linear element, which signals have frequencies given by the sum and difference of the products of n_1 times the first carrier signal and n_2 times the second carrier signal, where n_1 and n_2 are integers.

WHAT WE CLAIM IS:–

A method of detecting random junctions non-linearly responsive to incident oscillatory energy comprising, radiating energy from a first source of a first frequency f_1 and from a second source of a second frequency f_2 where f_1 and f_2 are not harmonically related, permitting energy from both said sources to impinge on at least one non-linear junction, whereby said junction responds to said energy to produce energy of a third frequency $n_1 f_1 \pm n_2 f_2$ where n_1 and n_2 are integers.

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1527399 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

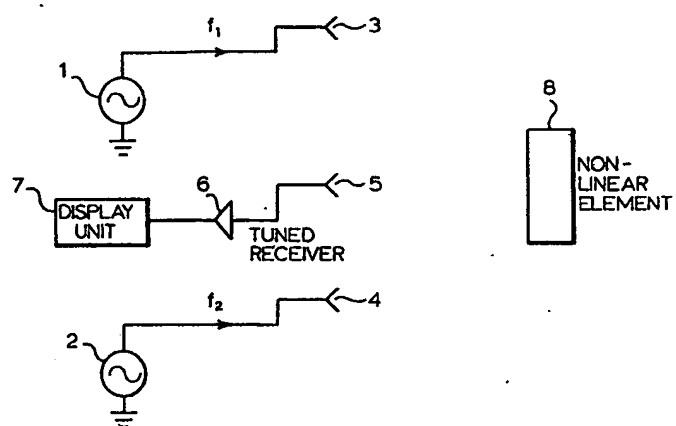

FIG. 1

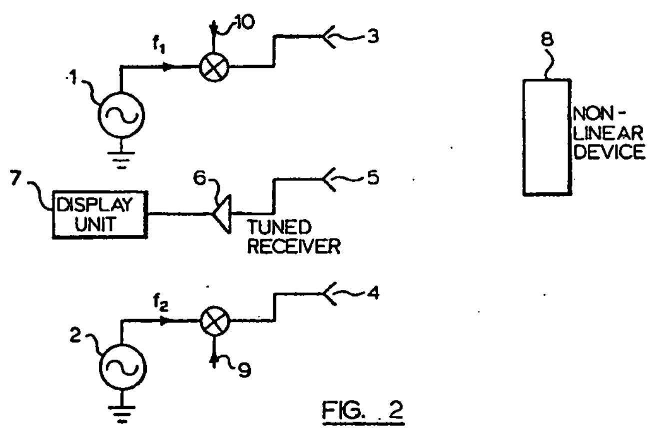

FIG. 2

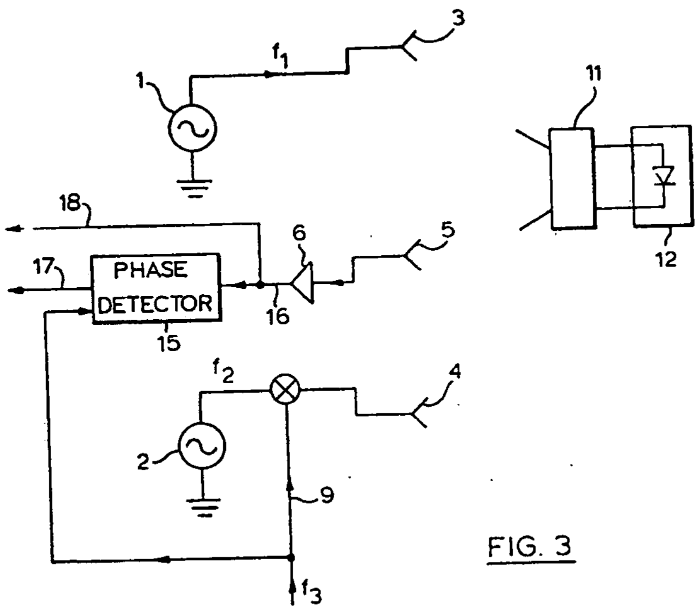

FIG. 3

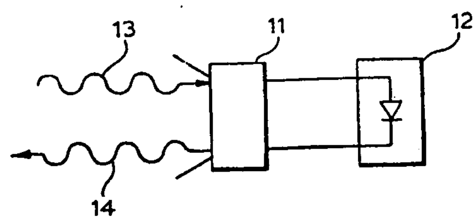

FIG. 4